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# Micro-encapsulated PCM in concrete matrix after a decade of the building construction

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**Abstract**

The reduction of the energy consumed in the building sector is no more a recommendation, but a duty of our society. Thermal energy storage (TES) implementation into buildings envelope has been highlighted as a promising technology to reduce the energy demand in buildings. Last decade, many literature have been dealing with the effect of the inclusion of latent heat storage materials in construction materials to provide higher thermal inertia. Several studies focused on the evaluation of the thermal properties, density, or porosity of these new materials. However, few of them focused on the long stability properties of the materials with embedded PCM when included in a building, since the lifetime of a building last around 50 years. In this study, an evaluation of a house-like cubicle of concrete with micro-encapsulated PCM after a decade of its construction is done. The results of this study were compared to the tests done in 2005 concluding that the thermal performance of this cubicle presented no degradation in the PCM effect.

Keywords: micro-encapsulated PCM, concrete with PCM, thermal energy storage, buildings

## 1. Introduction

Buildings use 32% of global final energy demand, and generate 30% of energy-related $CO_2$ emissions, and approximately one-third of the black carbon emissions. Over 60% of residential and almost 50% of commercial buildings use thermal energy, with higher contribution from water heating in residential buildings and from cooling in commercial ones. The drivers of the heating and cooling energy demand in buildings shows a clear tendency where the decrease of the energy demand is a necessity (Urge-Vorsatz et al. 2015).

Thermal energy storage (TES) is one of the highlighted technologies to achieve this aim. The integration of TES in buildings is of much interest to achieve a better final user acceptance of the technology. It is well known that improvements in the building envelope have high influence in the energy demand reduction. The use of phase change materials (PCM) in the building envelope has been widely studied to take profit of the latent heat stored during the phase change. The implementation of PCM as a passive system became a way to provide thermal inertia to the building at a specific temperature, in this case the comfort building temperature range (Navarro et al. 2016).

Different methodologies can be used to insert PCM in buildings such as direct incorporation, immersion, vacuum impregnation, encapsulation, shape-stabilisation, and form stable composites. However, when including PCM into a construction material during the mixing process, such as concrete or cement mortar, the one that prevents the leakage problem is micro-encapsulation method. This method consists of encapsulate small PCM particles (1 μm - 1000 μm) in a thin solid shell which is made from natural and synthetic polymers.

Cabeza et al. (2007) published an experimental study about two cubicles made of prefabricated concrete panel, one of them has a conventional concrete and the other one has 5wt.% of micro-encapsulated PCM. Both cubicles were tested under real summer weather conditions. Results showed that the cubicle with PCM provides more stable temperature conditions in the internal ambient and a delay of the maximum peak temperature.

The durability of building materials with PCM or the behaviour of the micro-capsules inside these matrixes are not usually taken into account in most of the published studies so far. However, these properties are considered of significant interest for builders, architects and building engineers, to achieve better acceptance on these new materials.

For this reason, after more than a decade, the summer experimental campaign was repeated to observe any difference or degradation in the concrete with PCM cubicle. In this paper, a comparison between the initial performance of the concrete with PCM system and the current status is presented.

## 2. Experimental set-up

In the experimental setup of Puigverd de Lleida (Spain), two house-like cubicles made of prefabricated concrete panels of 0.12 m of thickness were used in this study. These cubicles were built in 2005 within a European project framework (MOPCON). Both cubicles have the same dimensions (2.4×2.4×2.4 m) and orientation (N-S, 0°), but one of them have conventional concrete, and the other one 5wt.% of micro-encapsulated PCM in the concrete matrix (Figure 1). This fact allows the authors to evaluate and compare the effect of PCM incorporation in these construction systems.

The windows are also distributed with the same pattern in both cubicles, having one at the east and west wall, and four windows in the south wall, as well as the metallic door located in the north facade.

Figure 1. Construction of the cubicles with prefabricated concrete panels in 2005 at the experimental setup of Puigverd de Lleida (Spain)

In this application the PCM was implemented as a passive cooling system to avoid high temperatures in summer season. For this reason, just three panels of concrete with PCM were installed in the southern and western walls, and in the roof. The PCM selected was a commercial micro-encapsulated (Micronal DS 5001) with a melting point of 26 °C, and a phase change enthalpy of 110 kJ/kg.

The cubicles were instrumented to be able to measure and analyse their thermal performance with:

- Temperature of internal wall surfaces (east, west, north, south, roof and floor) and also external south wall temperature.
- Indoor temperature and humidity of the cubicle.

Moreover, the meteorological station registered outdoor temperature and humidity, solar radiation and wind velocity and direction. All the data was collected every 5 min interval in the data loggers of the facility.

In order to analyse the performance of the concrete with PCM system after a decade of the cubicle construction, the same experiments from Cabeza et al. (2007) were performed in the facility. During the summer period, the evaluation of both concrete cubicles was done in free floating conditions, where no cooling system was used, hence the evolution of the temperatures can be compared.

On the other hand, the compressive strength was tested in 2005 once the concrete was hardened, following the relative European standard UNE-EN 12390-3 and UNE-EN 12504-1. The same tests were performed to compare the properties of the concrete with PCM after a decade. Therefore, two cylindrical specimens were extracted one from the conventional concrete cubicle, and the other one from the concrete with PCM cubicle (Figure 2).


Figure 2. Concrete test samples extracted from both cubicles

## 3. Results

In the experiments performed during summer, as previously mentioned, free floating conditions were tested in both cubicles. From all the experimental campaign, some selected and representative results are showed in this study to demonstrate the thermal performance of the concrete with PCM system after a decade.

The internal ambient temperatures from both cubicles can be compared in Figure 3. Since the free floating conditions experiments do not have cooling supply both cubicles have difficulties to maintain the ambient temperature inside the comfort zone. However, the internal ambient temperature of the concrete with PCM cubicle is always below the one in the conventional concrete cubicle. In addition, the concrete with PCM cubicle present lower temperature fluctuation between day and night.

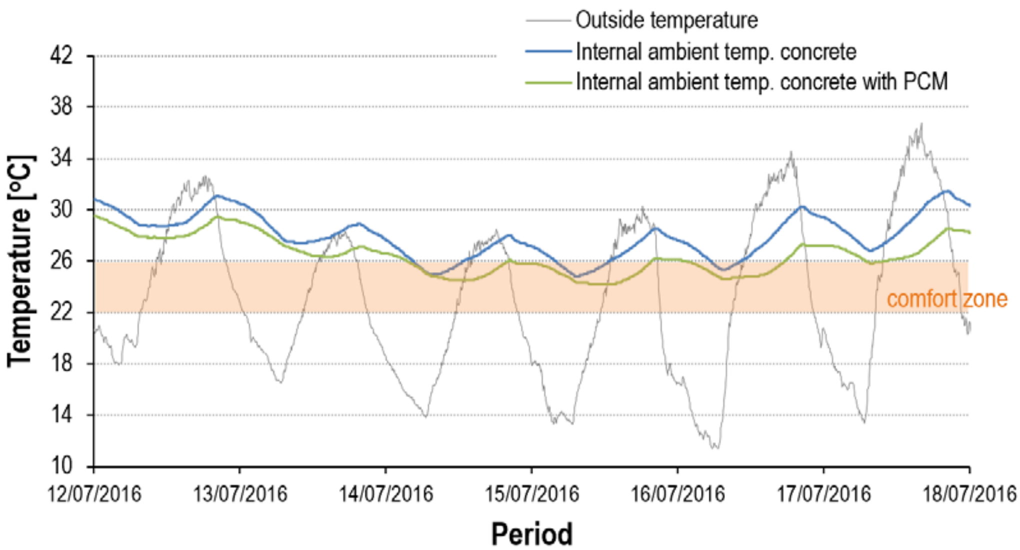


Figure 3. Outside ambient temperature and internal ambient temperature from both cubicles in 2016

Taking a look to the external surface temperature from the South wall, big differences can be observed between the two cubicles (Figure 4). Convencional concrete cubicles have higher peak temperatures compared to the concrete with PCM one. Maximum temperatures achieved in the south external surface wall in conventional concrete cubicle are between 34 °C and 39 °C, while in the one with PCM mostly are around 28 °C. Looking at Figure 4 the PCM effect is clearly observed, which store the heat coming from high temperature peak hours.

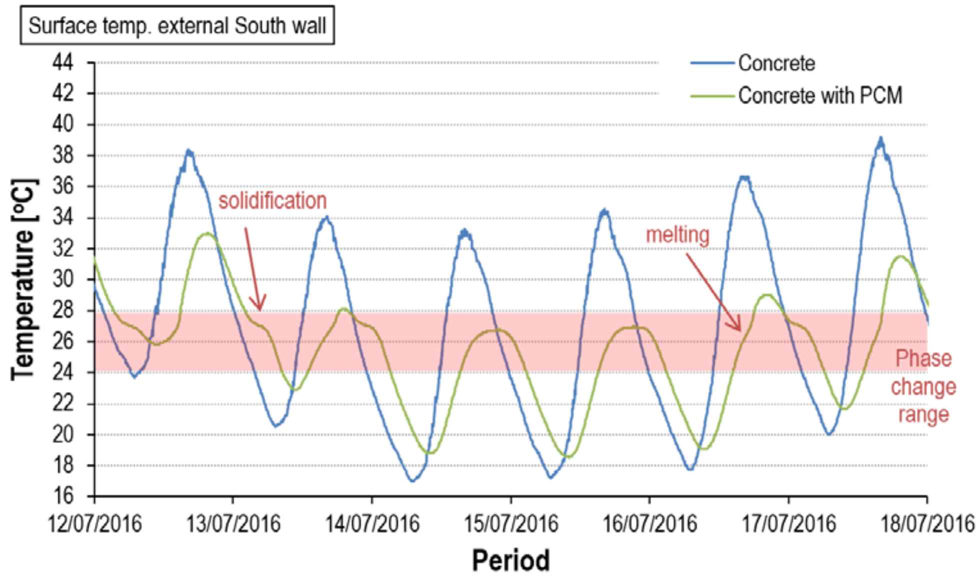


Figure 4. Surface temperature from the external South wall of conventional concrete and concrete with PCM cubicles (12 – 18 July 2016)

Another example of the PCM effect can be observed in Figure 5, where the solidification and melting process are clearly seen. Also, a delay on the maximum peak temperature is observed in the concrete with PCM cubicle compared to the conventional concrete cubicle.

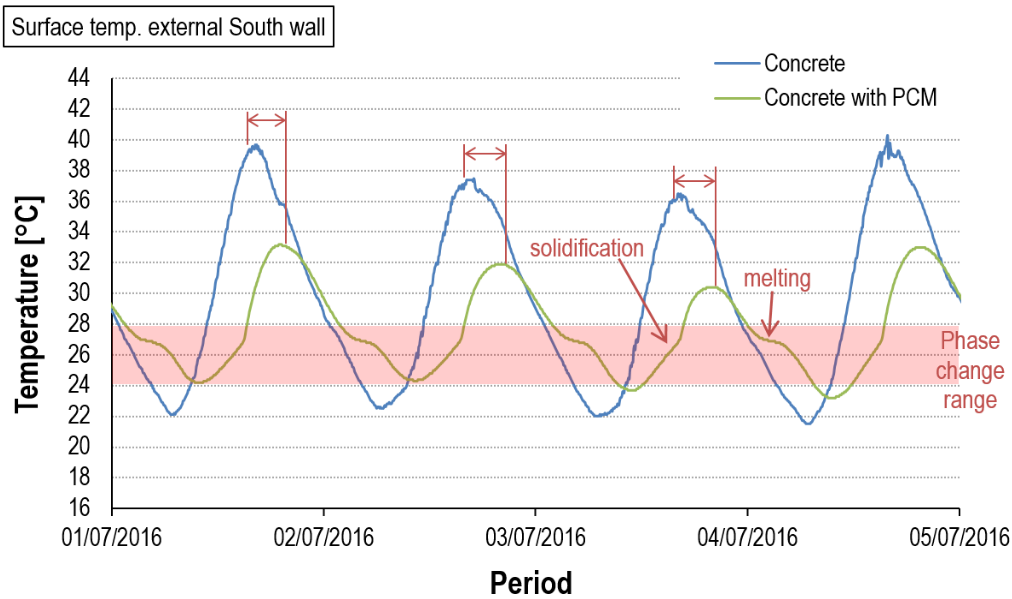


Figure 5. Surface temperature from the external South wall of conventional concrete and concrete with PCM cubicles (1 – 5 July 2016)

From these experiments authors have observed that the PCM incorporated in the concrete matrix is correctly working, storing the heat from daily peak hours and releasing it later, once the outdoors temperature is dropping down.

The results from the experiments presented in this study were compared to the ones published in the study of Cabeza et al. (2007). The effect observed in experiments performed in 2005 were the same as the ones seen nowadays. As an example, in Figure 6 the external surface temperature of the south wall in the concrete with PCM cubicle shows lower peaks compared to the conventional concrete. Also, the solidification and melting process of the PCM added in the concrete are clearly reflected in the external surface temperature.

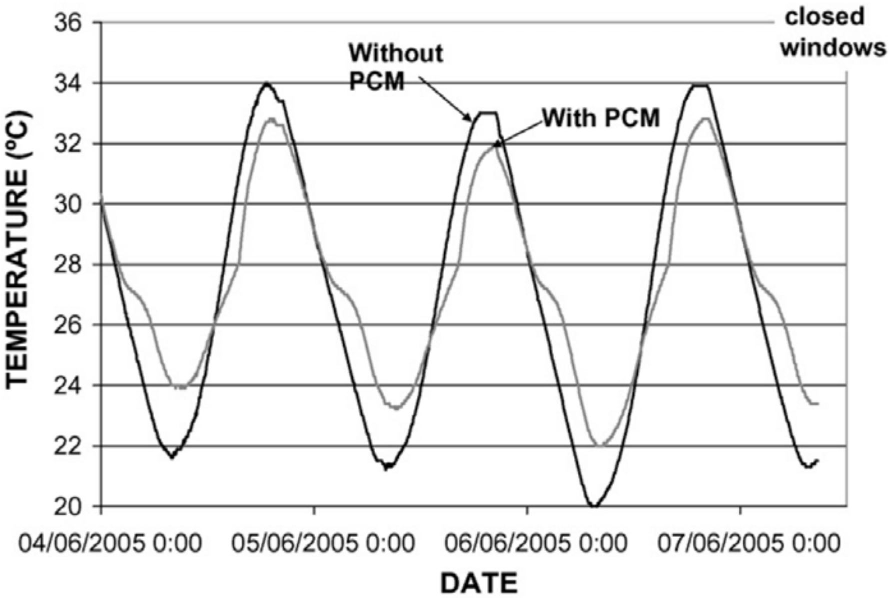


Figure 6. Temperature evolution of the external surface south wall in both cubicles, 2005 experiments (Cabeza et al. 2007)

In addition, the authors in Cabeza et al. (2007) concluded that the effect of PCM included in the concrete matrix contributed to a temperature reduction in the internal ambient of the cubicle.

Besides the thermal performance of the cubicles, the same compressive strength tests done in 2005 were performed for this study. The samples obtained from the cubicles with and without PCM had the same dimensions and the test followed the same European standards. Results presented no significant differences between the values obtained in 2005 (Table 1), hence in this aspect concrete with PCM has not experimented any change or degradation.

Table 1. Results from the compressive strength test of concrete samples with and without PCM, in 2005 and nowadays

| Test samples | | Compressive strength ($N/mm^2$) |
|---|---|---|
| Concrete + PCM (1) | In 2005 | 15.12 |
| Concrete + PCM (2) | | 12.86 |
| Concrete + PCM | Nowadays | 14.93 |
| Concrete (1) | In 2005 | 31.76 |
| Concrete (2) | | 31.33 |
| Concrete | Nowadays | 23.00 |

## 4. Conclusions

The use of phase change materials in buildings have been widely studied in different aspects, thermal properties, density, porosity, among others. However, when including these materials in buildings there is no literature about their performance along the years. Within this framework, the aim of this study was to evaluate the thermal performance nowadays of two house-like cubicles built in 2005. Both cubicles were built with prefabricated concrete panels, but one of them have conventional concrete, and the other one 5wt.% of micro-encapsulated PCM was added to the concrete matrix.

Based on the summer experimental campaign performed in 2005, this study replicates the same tests and the results are compared. The effect of PCM have been observed in the experiments presented in this study. Surface temperatures of the facades with embedded PCM were reduced, and consequently it was reflected in the delay of the peak temperature in the internal ambient and the smoother temperature fluctuations between day and night.

With these results authors can conclude that the cubicle with PCM showed the same thermal response obtained in 2005, observing no degradation in the thermal response of the PCM.

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